PSERC

Transmission Reliability Research Review
Locational Reserves

Responsive Reserve Market: Locational Scheduling and Pricing for Both Energy and Reserves

DOE (Washington)

12/9/2002

Outline

- Background
- The framework for locational scheduling and pricing --- co-optimization
- Results
- Ongoing and future work

Introduction

PSERC

- Ancillary Services (AS)

  "Services necessary to support the transmission of Energy from generators to loads, while maintaining reliable operation of the power system in accordance with good utility practice and reliability rules." [NYISO]

  - AS includes
    - Reactive Supply and Voltage Support Service
    - Black Start Capability
    - Frequency Response Service
    - Operating Reserve Service (traded in the wholesale market)

Introduction (Cont.)

PSERC

- Operating Reserve Markets (e.g., CA, NY, NE Electricity Market)
  - Regulation (AGC, load following)
  - 10-min spinning reserves
  - 10-min non-spinning reserves
  - 30-min non-spinning reserves
- Fixed Reserve (FR) Requirements
  - A given percentage of forecasted peak load
  - To be able to make up the loss of the largest unit
  - Combinations of both

FR Market Examples

PSERC

- NYISO locational reserve requirement http://www.nyiso.com/oasis/misc_pdf/nyiso_locational_reserve_reqmts.pdf

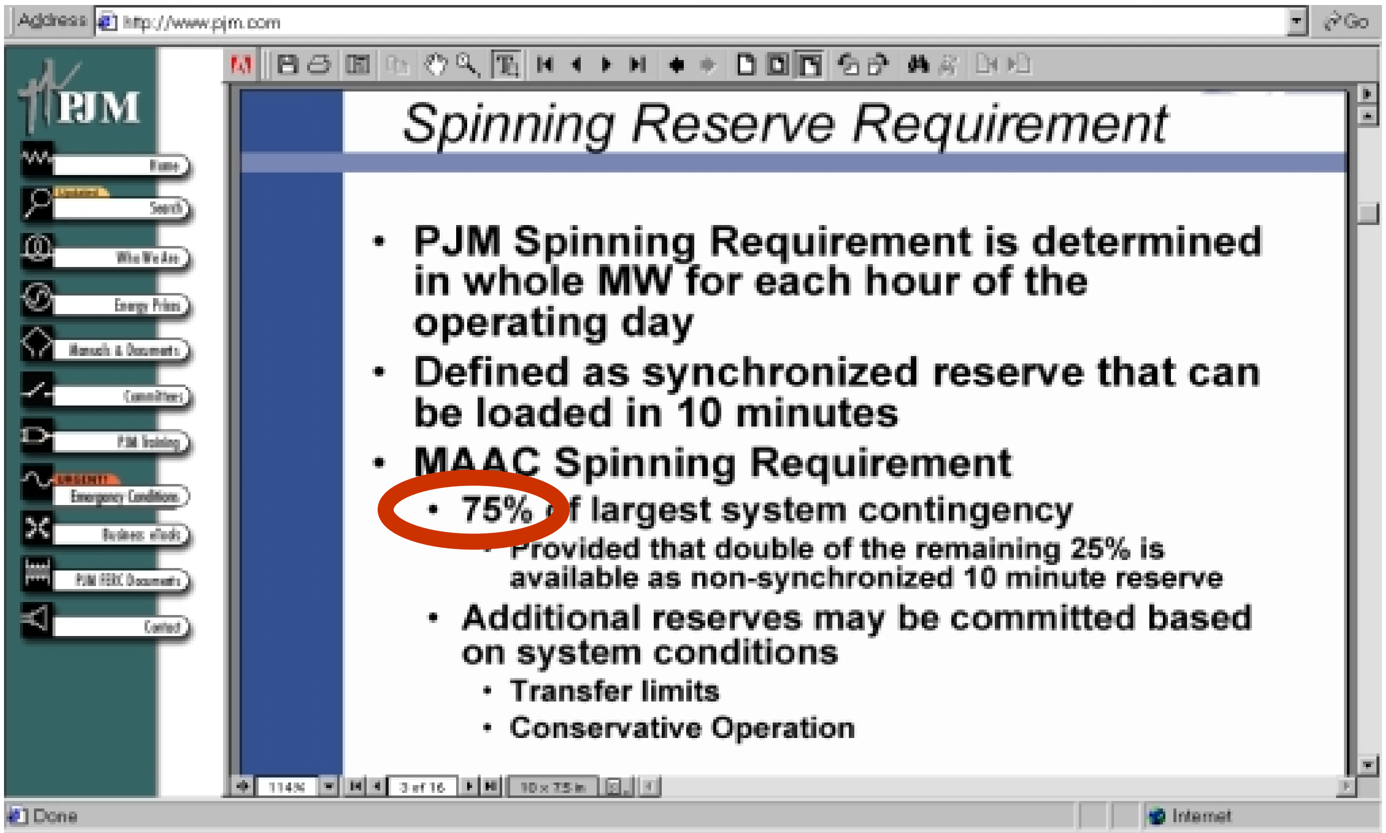
Table 2
Revised NYISO Reserve Requirements

	New York CA	Eastern New York	Long Island
Western=NY CA-Eastern-Long Island	A = most severe NYCA operating capability loss (1200MW)		
10 Minute Spinning Reserve	½ A = 600MW (I)	1/4 A = 300MW (IV)	1/20 A = 60MW (VII)
10 Minute Total Reserve	A = 1200MW (II)	1200MW (V)	1/10 A = 120MW (VIII)
30 Minute Reserve	1½ A = 1800MW (III)	1200MW (VI)	270-540MW (IX)

FR Market Examples (Cont.)

PSERC

- PJM spinning reserve requirement (plan to enforce Dec. 2002)



FR Market Cons

- Cons
  - Over-estimation of actually needed reserves
  - Actual reserves may not be locationally assigned as desired.
  - Consequences
    - Resources wasting: redundant reserves
    - Increased operating costs: some contingencies may not be covered but should have to, resulting in expensive solutions (expensive imports needed)
    - Potential market power problems: reserves in the load pocket

Proposed Market Alternative – Responsive Reserve (RR) Market

PSERC

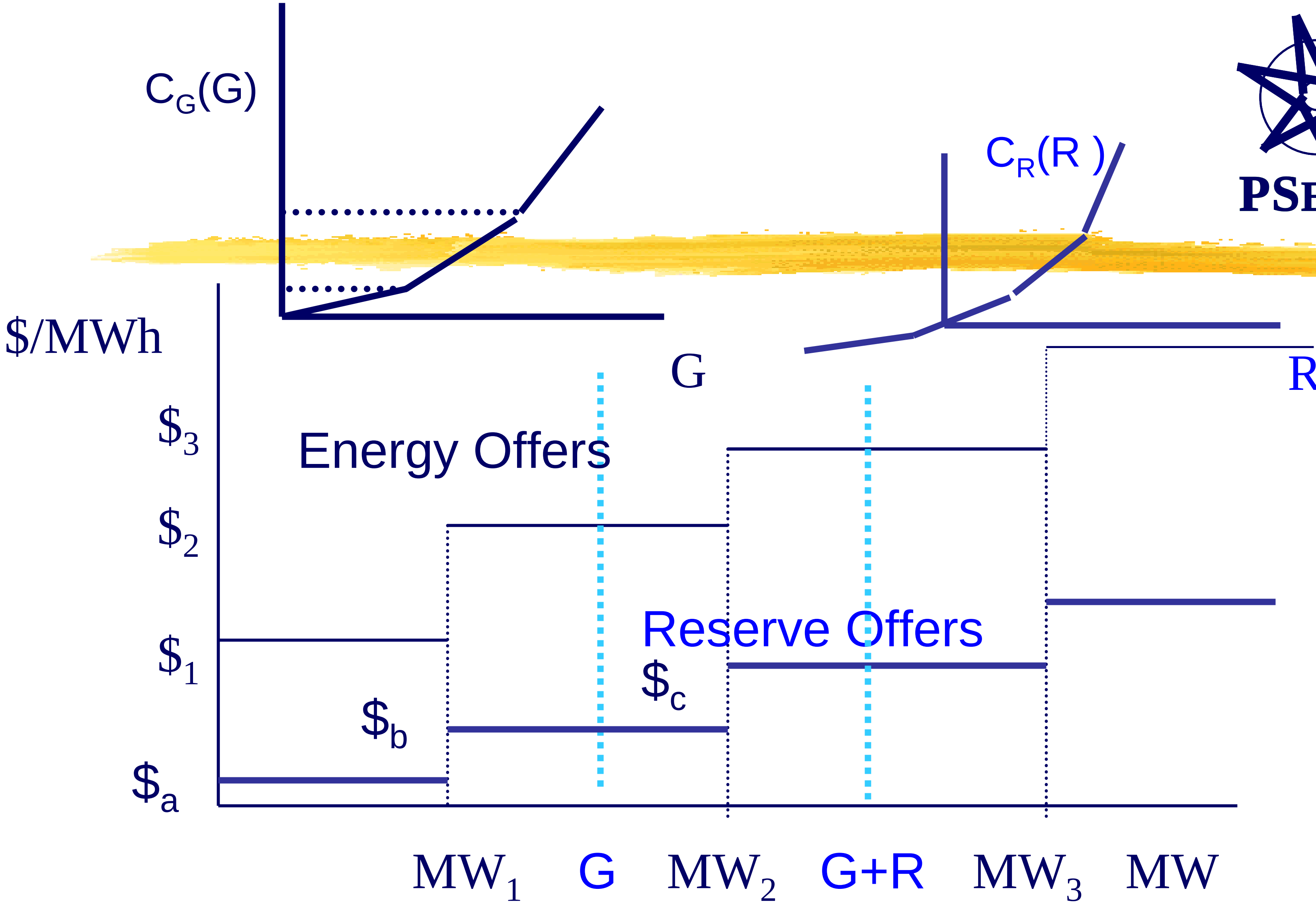
- No fixed forecasted reserve requirement
- Reserves required will cover a list of credible contingencies (unit failure, line-out, sudden load growth, etc.)
- The amount of reserves assigned varies with different system demands and energy-reserve offers – Responsive Reserves

Co-optimization

- Objective
  - minimize the total expected cost (operating energy cost plus the spinning reserve cost) over the predefined base case and credible contingencies

$$S = \sum_{k=0}^{K} p_k \sum_{i=1}^{N} \left[C_{Pi}(G_{ki}) + C_{Ri}(R_{ki}) \right] \qquad \sum_{k=0}^{K} p_k = 1$$

- Subject to network and system constraints
  - Generation capacity limits
  - Voltage limits
  - Line flow limits
  - Ramping limits



We can clear a market with offers for both energy and reserves. We can compute locational prices for both energy and reserves

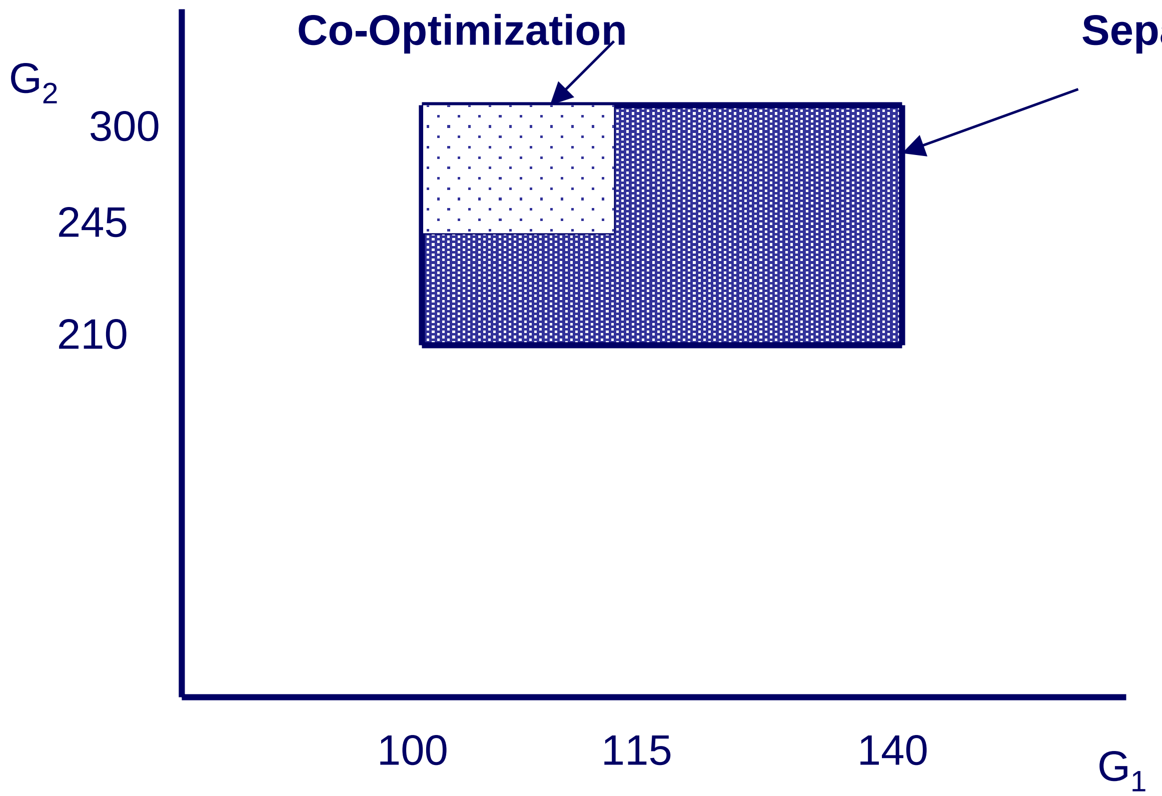
Co-optimization Solution Properties

- The co-optimization is K OPF's coupled by the reserve costs and the dependence of reserves on generation.
- The solution is generally different than K separate OPF's which do not consider the cost of reserves.
- The important features of the solution are the "Generator response intervals"

$$\hat{G}_{i\,min} \leq G_{ki} \leq \hat{G}_{i\,max}$$

- Not physical generator limits but the result of the co-optimization. K separate OPF's give large generator response intervals. Co-optimization reduces the size of the generator response intervals

"Generator Response Intervals"



Augmented Optimal Power Flow (AOPF)

PSERC

- Cost-minimizing optimization for one of the specified K systems (base case or a contingency)

$$f_k = \sum_{i=1}^{N} \left[C_{P_i}(G_{ki}) + C_{Ri}(R_{ki}) \right]$$

- Old system constraints from the Co-optimization apply Generation capacity limits, Voltage limits, Line flow limits, Ramping limits
- New (non-physical) generator constraints are added

$$\hat{G}_{i\,min} \le G_{ki} \le \hat{G}_{i\,max}$$

- Reserves are defined as

$$R_{ik} = G_i^{max} - G_{ik}$$

Properties of AOPF

PSERC

- If G_{ik} is the solution of the Co-optimization, it is also the solution of the k^{th} AOPF
  - Proof: like proof of principle of optimality
- Consequence:
  - if a new contingency can be met with the reserves from the co-optimization then the single AOPF gives the optimal solution.
  - Deals with forecast errors and unanticipated contingency. Prices from AOPF not Co-optimization
  - Only need to repeat the co-optimization when a new contingency can not be covered

Locational Energy and Reserve Prices

- Pricing for energy and reserves
  - incremental cost – "*the extra cost of producing an extra unit of output*" *[Stoft]*
- Nodal energy prices
  - Computation by perturbation
    - The optimum cost of the original AOPF is f_0.
    - Perturb the co-optimization, solve for the new generator response intervals.
    - Do the perturbed AOPF with new generator response intervals , new optimum cost is f_1
    - Nodal energy price = $f_1 - f_0$
- Generator-specific reserve prices

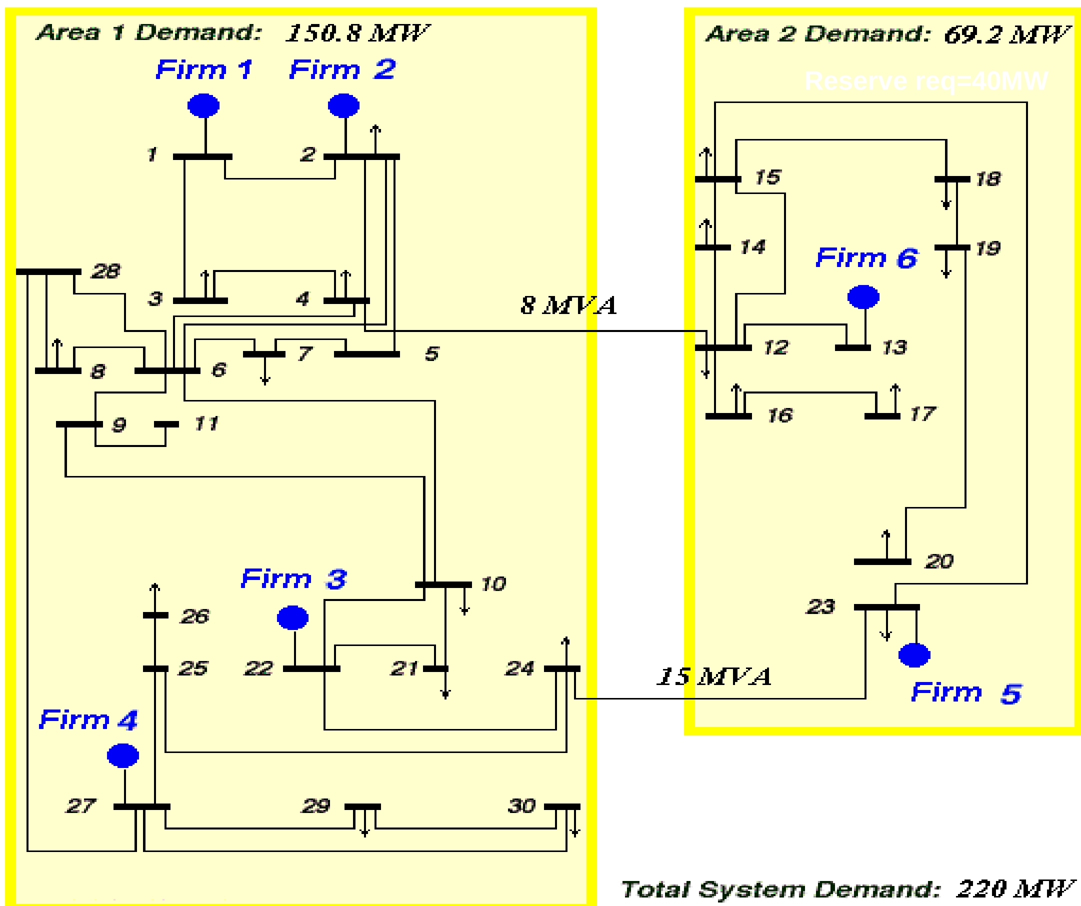
  Lagrange Multipliers of AOPF associated with reserve equality constraints:

$$R_{ik} = G_i^{max} - G_{ik}$$

PSERC

Preliminary RR Market Results

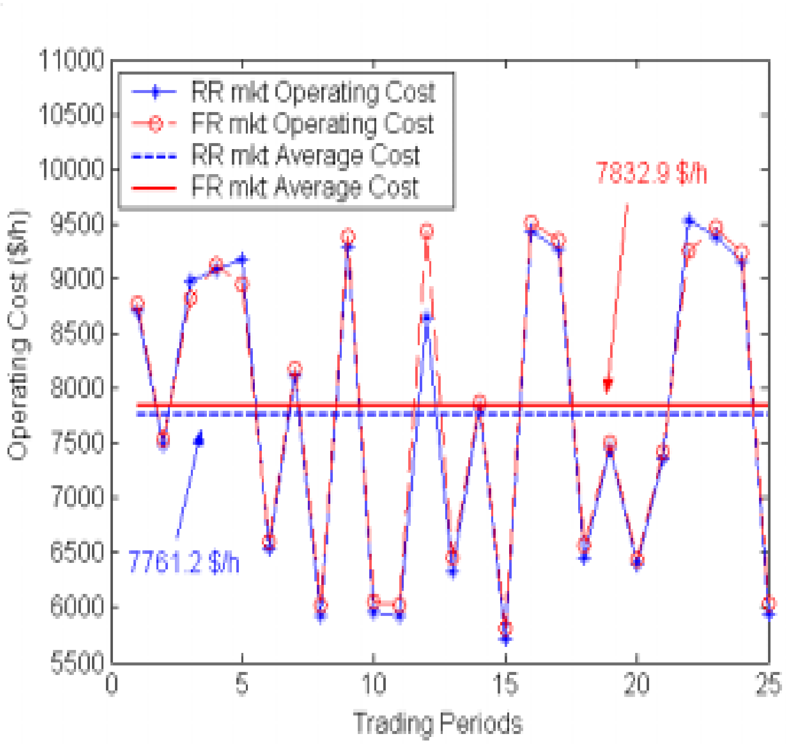
- Test system



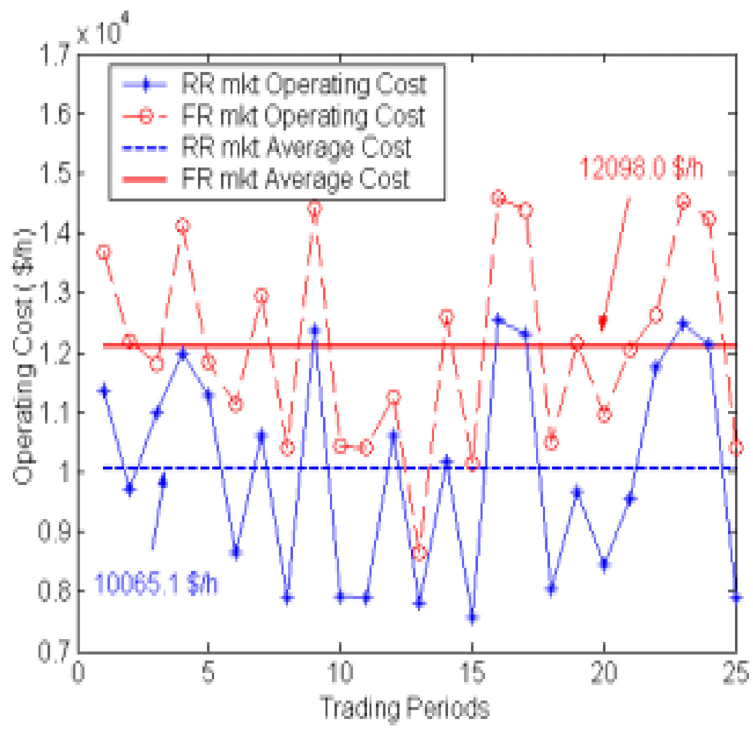
Preliminary RR Market Results

- Comparison of operating costs between Fixed and Responsive Reserve markets
  - Reduced operating costs for the RR market

Marginal Cost Offers

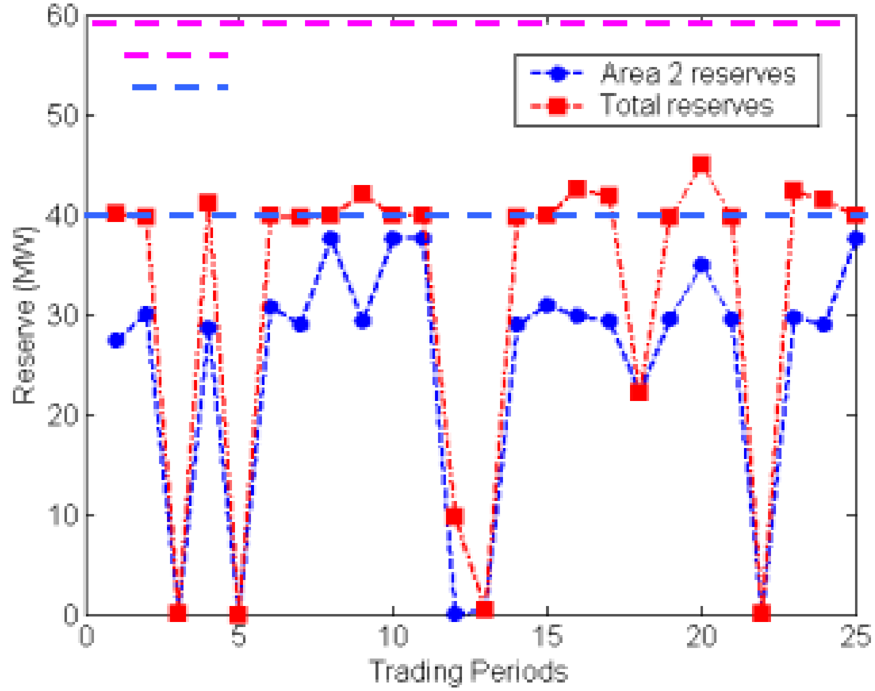


Simulated High Offers



Preliminary RR Market Results

- Comparison of the amount of reserve requirement between FR and RR markets
  - Require less reserves in the RR market

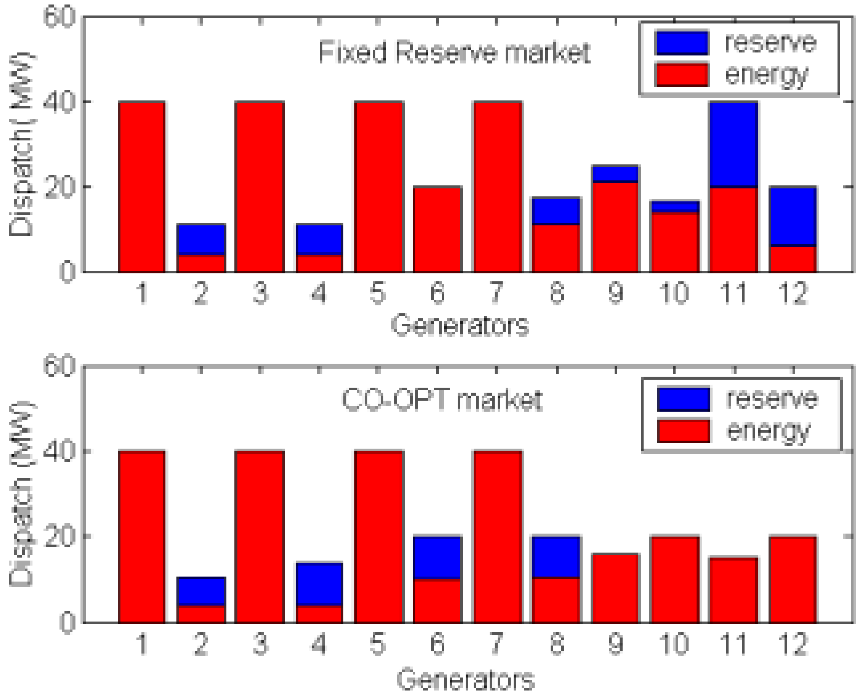


DOE (Washington)

12/9/2002

Preliminary RR Market Results

- Reasons that the RR market outperforms the FR market
  - Aim at minimum reserve requirement to cover specified cases
  - Optimal way of locationally assigning reserves



Experiments

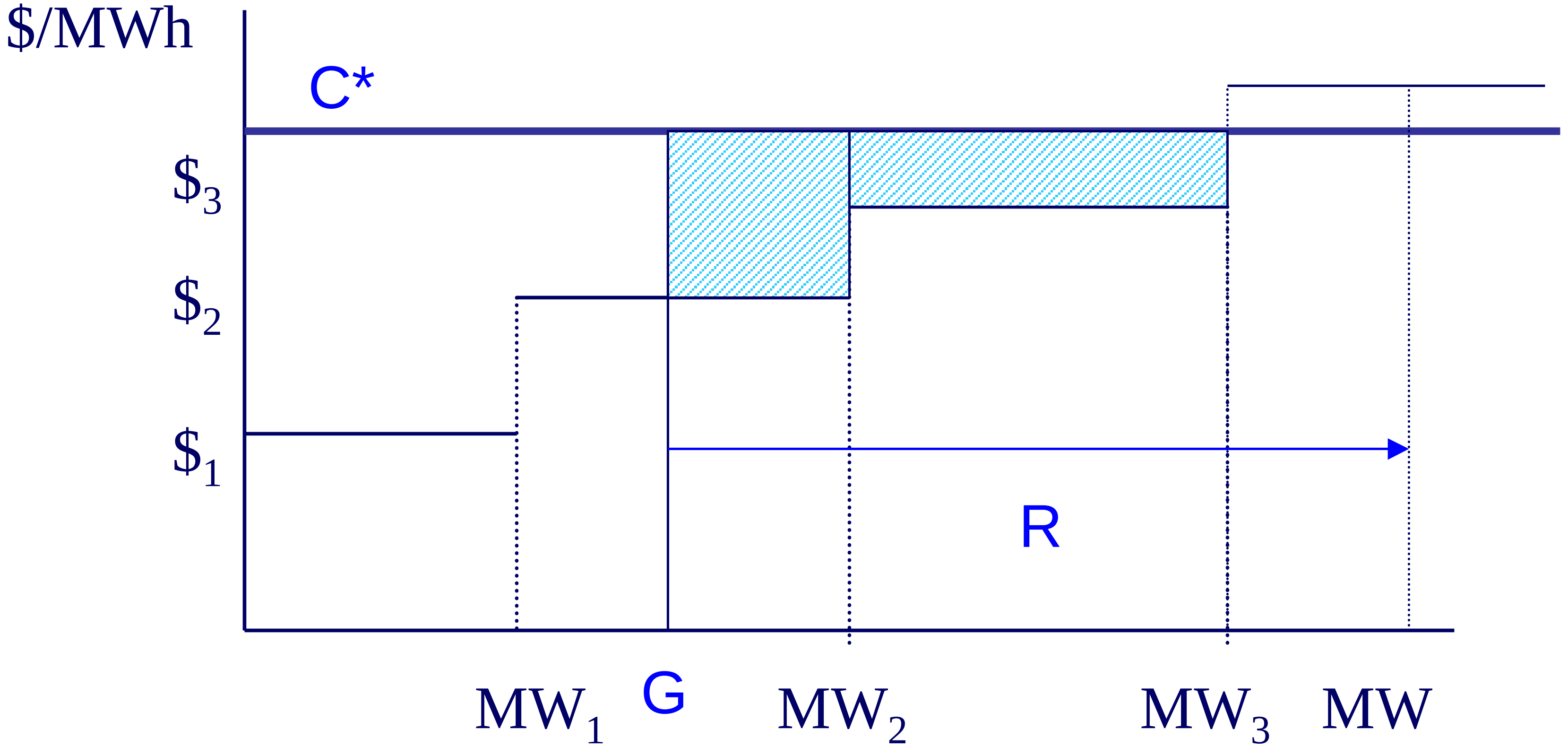
- RR market experiments
  - Whether or not the RR market is more efficient in revealing true generator costs
  - Whether or not the RR market is more difficult to exploit when market power is a potential problem.

Prices: Incremental Cost (IC)? Decremental Cost (DC)? Or Shadow Prices (SP)?

PSERC

-
    - Shadow prices correspond to dual variables or Lagrange multipliers
    - Most of the time, DC = SP = IC
    - When there are redundant constraints or the optimum point is at a “special” corner, DC < IC, and SP is a random number within the interval [DC, IC] depending upon the solver and the iteration starting point and step sizes
        - The dual problem has multiple solutions
    - DC <= SP <= IC

Opportunity Costs: Attempt to lower energy offers. Depends on energy offers and an energy price. (possibly from the day ahead market)



Nodal or Generator-specific Reserve Prices ?

- Generator-specific prices
  - Lagrange Multipliers of AOPF associated with reserve equality constraints: $R_{ik} = G_i^{max} - G_{ik}$
- Nodal prices
  - Computation by perturbation
    - The optimum cost of the original AOPF is f_0.(for each load)
    - Perturb the co-optimization, solve for the new generator response intervals.
    - Do the un-perturbed AOPF with new generator response intervals, new optimum cost is f_1
    - Nodal reserve price = $f_1 - f_0$

Prices by Direct Computation

PSERC

- Prices by perturbation are very time-consuming

It is desirable to obtain prices without doing perturbations

$$\text{Energy price} = \lambda_{\text{energy}} + \sum \lambda_{G\min \text{ or } G\max} \left[\frac{\Delta G_{\text{min or max}}}{\Delta \text{load}} \right]$$

where λs are from the AOPF

Remaining problem: How to calculate without doing perturbations

$$\frac{\Delta G_{\text{min } or \text{ max}}}{\Delta load}$$

Other Challenges

- Unit commitment
  - Consider inter-temporal issues: start-up/show-down cost, minimum up/down time, etc.
- Scalability problem
  - How to do for a system with thousands of nodes?
    - Does not seems possible to implement the full AC flow for the co-optimization.
    - Use the linearized system to do the co-optimization and full AC system for the AOPF.